

## TITLE

**[0001]** Battery Electrode Assembly and Fabrication Method Therefor

## FIELD

**[0002]** This invention relates generally to batteries suitable for use in  
5 implantable medical devices and more particularly to an electrode assembly  
configured for use in such batteries and a method for fabricating such an  
assembly.

## BACKGROUND

**[0003]** A variety of implantable battery operated medical devices are available  
10 and/or under development for treating a wide range of physiological  
insufficiencies. Such devices uniformly require batteries which are small, light,  
safe, and reliable. It is additionally generally important that the batteries exhibit a  
high energy density and that they be amenable to implementation in a wide  
range of shapes and sizes to best utilize the space available in a medical device  
15 housing. Other applications in which size, safety, and reliability are desirable  
include aerospace and hybrid electric vehicle applications.

**[0004]** A significant challenge in battery design and construction is to provide  
an electrode assembly which can be readily manufactured and whose attributes  
are consistent with a battery implementation possessing the aforementioned  
20 characteristics.

**[0005]** The prior art reveals an abundance of electrode assembly  
configurations for use in batteries including configurations of stacked planar

electrodes and configurations of rolled sheet electrodes. A typical stacked electrode design comprises a multiplicity of planar layers including positive electrodes (+), negative electrodes (-), and separator sheets (s) stacked in an exemplary sequence as follows: -, s, +, s, -, s, +, s, etc. Stacked electrode configurations frequently use tabs extending from the positive electrodes which are electrically interconnected to form a positive current collector. Similarly, tabs extending from the negative electrodes are electrically interconnected to form a negative current collector. The positive and negative current collectors are generally connected to first and second terminals extending externally of the battery case. In some configurations, the battery case functions as one of the external terminals.

**[0006]** Although known stacked electrode configurations using tabs may be suitable for use in certain applications, significant challenges are encountered when attempting to use such configurations for medical applications having small size and high energy density requirements. For example, stacked electrodes with tabs generally consume, or waste, headspace within the battery case. Thus, the energy density of a battery using conventional stacked and tabbed electrodes is constrained by the wasted headspace. Moreover, some conventional stacked designs do not lend themselves to easy fabrication and as a result manufacturing costs can be relatively high and reliability problems can be encountered.

## SUMMARY

**[0007]** The present invention is directed to an enhanced electrode assembly, and construction method therefore, intended for use in small high performance batteries suitable for implantable medical device applications.

5 **[0008]** An electrode assembly in accordance with the invention is characterized by a stack of precisely aligned planar elements including alternately arranged positive and negative planar electrodes and wherein a planar separator is interposed between adjacent electrodes. Each electrode is preferably preformed of a thin metal substrate carrying active material on front  
10 and rear substrate faces. As an example, a positive electrode may typically comprise an aluminum substrate having a thickness of 10 to 30 microns, preferably 20 to 30 microns, and carry positive active material on each substrate face having a thickness of 30 to 120 microns. Similarly, a negative electrode may typically comprise a titanium substrate having a thickness of 5 to  
15 20 microns, preferably 5 to 12 microns with negative active material on each face thereof having a thickness of 30 to 120 microns. Each separator interposed between adjacent electrodes typically has a thickness of 20 to 30 microns. The planar elements, i.e., positive and negative electrodes and separators, have peripheral edges which are substantially identically shaped and similarly  
20 dimensioned.

**[0009]** In accordance with an important aspect of a preferred embodiment, the peripheral edge of each electrode substrate defines an active area and a tab extending therefrom. The front and rear faces of the active area each carries a

layer of active material. The faces of the tab area are preferably bare. The positive electrode tabs are all located at a first position along the peripheral edge whereas the negative electrode tabs are all located at a second position spaced from said first position.

5    **[0010]**    In accordance with a further important aspect of the preferred embodiment, each of the bare substrate tabs carries a clip, i.e., a planar metal piece folded around the outer tab edge, to form a reinforcing strip adjacent each tab face. In assembly, each clip is crimped over the tab, and optionally welded thereto, to provide tab mechanical reinforcement as well as electrical continuity  
10    from the electrode substrate to the clip. Each clip and its captured tab is trimmed to define a reference edge and pierced to form first and second alignment holes spaced from the edge extending through the clip and tab.

**[0011]**    During assembly of the electrode stack, the clip/tab alignment holes are used in conjunction with registration pins to precisely align the multiple planar  
15    electrodes and separators. More particularly, the positive electrode alignment holes are fitted onto a first pair of registration pins and the negative electrode alignment holes are fitted onto a second pair of registration pins. The pins can either be removed prior to final assembly or can remain in the finished stack to maintain alignment and provide additional fastening. Various pin configurations  
20    can be used, including, for example, expandable tubular fasteners.

**[0012]**    Each separator preferably also has a tab extending from its peripheral edge. The separator tab is pierced to form two alignment holes. During assembly of the electrode stack, a separator panel is interposed between

adjacent electrodes with a first separator alignment hole aligned with one of the positive electrode alignment holes and a second separator alignment hole aligned with one of the negative electrode holes.

**[0013]** Thus, in the assembled electrode stack, the positive electrode clips are aligned to form a positive clip column. Similarly the negative electrode clips are aligned to form a negative clip column which extends parallel to, but spaced from, the positive clip column. The tabs of the interposed separators laterally bridge the positive and negative clip columns. Compression of the respective clip columns acts to pinch and hold the separator tabs to rigidify the entire stack.

10 In accordance with an important aspect of a preferred embodiment, the clip thickness dimension is selected so that each clip in a column abuts adjacent clips in the same column. This arrangement enables the clips in each column to be readily welded together to provide excellent electrical interconnections and mechanical rigidity.

15 **[0014]** Electrode assemblies in accordance with the invention can be fabricated in a wide range of shapes and sizes. Although the exemplary electrode assembly described in detail hereinafter is configured to fit within a rectangular prism battery case, other assembly embodiments can be readily configured to conform to other case shapes.

## 20 BRIEF DESCRIPTION OF THE FIGURES

**[0015]** Figure 1 is an isometric view, partially broken away, showing a battery in accordance with the present invention;

**[0016]** Figure 2A is an isometric view of a planar electrode in accordance with the invention having a substrate tab adapted to receive a clip thereon;

**[0017]** Figure 2B is an end view of the planar electrode of Figure 2A;

**[0018]** Figure 3 is an isometric view showing the planar electrode of Figure 2A  
5 with the clip crimped thereon;

**[0019]** Figure 4 is an isometric view similar to Figure 3 showing the clip and tab after being trimmed to form a reference edge;

**[0020]** Figure 5 is an isometric view similar to 4 showing the clip and tab after piercing to form two alignment holes;

10 **[0021]** Figure 6 is an isometric exploded view of an electrode stack in accordance with the invention showing how positive and negative electrodes and separators are sequenced to form the stack;

**[0022]** Figure 7A is a sectional view taken substantially along the plane 7A-7A of Figure 6;

15 **[0023]** Figure 7B is a sectional view taken substantially along the plane 7B-7B of Figure 6;

**[0024]** Figure 8A is a top view of a portion of the stack of Figure 6 showing preferred top weld areas;

**[0025]** Figure 8B is a fragmentary end view of the upper portion of the stack of  
20 Figure 6 showing a preferred side weld area;

**[0026]** Figure 9 is an isometric view depicting a typical stacking fixture used to assemble the stack of Figure 6;

[0027] Figure 10 is a front view of an electrode showing the use of noncircular alignment holes in the tab/clip;

[0028] Figure 11A is a front view showing a further alternative arrangement in which a portion of the clip is deleted to provide access to the underlying substrate  
5 for welding;

[0029] Figure 11B is an isometric view of a stack utilizing tabs configured as shown in Figure 11A; and

[0030] Figure 12 is an isometric view showing an alternative two panel separator.

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#### DETAILED DESCRIPTION

[0031] Attention is initially directed to Figure 1, which illustrates a battery 20 having a case 22 which is shown partially broken away, to reveal an interior volume containing an electrode assembly 24. Figure 1 also illustrates battery terminals 26 and 28 extending from the assembly 24 in the case interior volume  
15 to the case exterior for supplying power to an electric load (not shown). The depiction of the battery 20 in Figure 1 is generally representative of prior art battery constructions to the extent it employs a sealed case 22 to house an electrode assembly 24 and a suitable electrolyte (not shown) together with terminals 26 and 28 extending from the case interior volume through the case  
20 wall. The present invention is primarily directed to an enhanced electrode assembly structure and a method for fabricating that structure. An electrode assembly in accordance with the present invention can be utilized in conjunction with various known battery chemistry technologies but, for convenience

hereinafter, the described preferred embodiment will be assumed to utilize lithium ion battery chemistry.

**[0032]** Batteries using an electrode assembly comprising stacked planar elements are well known in the art. Such known stacked assemblies typically  
5 comprise a plurality of planar positive electrodes and a plurality of planar negative electrodes stacked in an alternating sequence with planar separators interposed between adjacent electrodes. Embodiments of the present invention employ a corresponding sequence of planar elements to form an electrode assembly stack but introduce innovations to enhance battery performance, e.g.,  
10 energy density, enhance reliability, and safety, and provide a convenient fabrication method at reasonable cost to yield small batteries suitable for demanding applications, e.g., for use in implantable medical devices.

**[0033]** Attention is initially directed to Figure 2A which illustrates a planar electrode 30 for use in an electrode assembly 24 in accordance with the present  
15 invention. The electrode 30 comprises a metal substrate 32 which may, for example, comprise aluminum foil for a positive electrode and titanium foil for a negative electrode. Suitable alternative substrate materials are discussed in the literature. A positive electrode substrate 32 typically has a thickness in the range of 10 to 30 microns, whereas a negative electrode substrate more typically has a  
20 thickness in the range of 5 to 20 microns. The substrate 32 is initially cut to define a peripheral edge 34 which bounds an active area 36 and a tab 38 extending from the active area 36. The substrate 32 also defines a front face 40 and a rear face 42. Active material layers 44 and 46 are respectively applied to



the front and rear faces 40 and 42 of the substrate active area 36. The tab 38 is left bare. The thickness of each active material layer is typically within the range of 30 to 120 microns.

**[0034]** In accordance with the invention, metal reinforcing strips 50 and 52 are respectively attached to the front and rear faces 54, 56 of the substrate tab 38. In accordance with the preferred embodiment the reinforcing strips 50 and 52 comprise first and second portions of an integral clip 58 bent along foldline 60. The clip 58 defines an interior foldline edge 62 and an exterior foldline edge 64. In accordance with the present invention, the clip 58 is mounted on the tab 38 with the clip interior foldline edge 62 proximate to the tab outer edge 65. After mounting, the clip 58 is crimped onto the tab 38 (Figure 3) with the clip portions 50 and 52 abutting, i.e., in direct contact with the faces 54, 56 of tab 38. After crimping, the clip 58 and underlying tab 38 are trimmed (Figure 4) to define a reference edge 70.

**[0035]** After or concurrent with the trimming step represented in Figure 4, the strip portions 50, 52 of the clip 58 and the underlying tab 38 are pierced in Figure 5 to define spaced alignment holes 72 and 74 which are precisely referenced to reference edge 70. Although they can be performed sequentially, the trimming step and piercing step preferably occur simultaneously.

**[0036]** It is pointed out that the electrode 30 depicted in Figures 2-5 shows a tab 38 located left of center along peripheral edge portion 35. As will be discussed hereinafter in connection with Figure 6, positive and negative electrodes are alternately stacked with all of the positive electrodes having tabs

located left of center along peripheral edge portion 35 and all of the negative electrodes having tabs located right of center along peripheral edge portion 35.

**[0037]** More particularly, attention is now directed to Figure 6, which illustrates the manner of stacking positive and negative electrodes and separators in accordance with the present invention to form an electrode assembly 20. More particularly, Figure 6 illustrates a stack of planar elements 80 in which positive electrodes 82 are alternately stacked with negative electrodes 84 and in which planar separators 86 are interposed between each pair of adjacent electrodes.

**[0038]** Particularly note in Figure 6 that positive electrode 82 is depicted as in Figure 5 having a tab 38 with a reinforcing clip 58 thereon. The clip 58 and underlying tab have first and second alignment holes 72, 74 formed therein. Note in Figure 6 that the tabs 38 and clips 58 of all of the positive electrodes are aligned and form what may be referred to as a positive tab/clip column 90.

**[0039]** Whereas the tabs on the positive electrodes 82 are depicted as left of center along peripheral edge portion 35, the negative electrodes 84 are shown with tabs 38' and clips 58' which are located right of center along peripheral edge portion 35'. Note that the clips 58' also have first and second spaced alignment holes 72' and 74'. The tabs and clips of the negative electrodes in stack 80 are aligned along what may be referred to as a negative tab/clip column 92 extending parallel to and spaced from the column 90.

**[0040]** As shown in Figure 6, the separators 86 define a centrally located tab 94 defining spaced alignment holes 96 and 98. The tab 94 is intended to laterally bridge the spacing between the columns 90 and 92 in the stack 80.

More particularly, the tab 94 alignment holes 96 and 98 are intended to respectively align with the inner alignment holes of the positive and negative electrode tabs. That is, separator alignment hole 96 is intended to align with positive electrode alignment hole 74 and separator alignment hole 98 is intended to align with negative electrode alignment hole 72' in the stack 80 as depicted in Figure 6.

**[0041]** Attention is now directed to Figure 7A which shows a horizontal cross section through the tabs and clips of the stack 80 of Figure 6. The positive column 90 comprises multiple clips 58 each mounted on a different positive electrode tab 38. Each clip defines reinforcing strips 50, 52 dimensioned so that adjacent clips substantially abut one another. More particularly, each clip preferably has a thickness equal approximately to the sum of the thickness of a positive electrode plus a negative electrode plus two separators. This enables adjacent clips in the positive column 90 to confront and abut one another.

**[0042]** The negative column 92 is depicted similarly to column 90 and it, too, comprises clips that are dimensioned to substantially abut one another. It is important to recognize however that Figure 7A also depicts the separator tabs 94 interposed between and bridging the columns 90 and 92. Note particularly that the separator tabs 94 extend somewhat diagonally between the alignment holes 96 and 98 because the positive and negative electrodes are alternately stacked. That is, as can be seen in Figure 6, the portion of the separator tab 94 around alignment hole 96 bears against the portion of clip 58 around alignment hole 74. However, the portion of the same tab 94 around alignment hole 98 bears against

the portion of clip 58' around alignment hole 72' of an adjacent negative electrode 84. Since the positive electrodes and negative electrodes are stacked, i.e., layered and thus misaligned, the tab 94 bends essentially diagonally as shown in Figure 7A. As a consequence of this diagonal bending, adjacent separator tabs 5 94 form a V shape 100, which acts to lock and prevent the relative lateral movement of any of the tabs and clips. It is also pointed out that the separator tab 94 assists in holding together the interleaved positive and negative electrodes. That is, the welded positive electrode tabs secure together a substack of positive electrodes and the welded negative electrode tabs secure 10 together a substack of negative electrodes. Inasmuch as the separator tabs 94 are captured between clips of both the positive and negative clip columns, the separators additionally function to add rigidity to the stack and prevent any relative lateral movement.

**[0043]** Figure 7B depicts a cross section of the stack 80 showing 15 separators 86, positive electrodes 82, and negative electrodes 84. Note that Figure 7B also depicts how each of the electrodes comprises a substrate 42 having active material layers 44, 46 on respective faces thereof as previously shown in Figure 2B.

**[0044]** In order to stack the positive and negative electrodes and separators in 20 precise alignment, it is preferable to use registration pins in combination with the aforementioned alignment holes. Figure 9 illustrates an exemplary stacking fixture 120 having a stacking base 122 and a plurality of fixedly positioned alignment or registration pins 124. The pins 124 include outer pins 126 and 128

and inner pins 130 and 132. The alignment pins 124 are fixedly located and spaced relative to one another so that the positive and negative electrodes and separators can be precisely stacked thereon. Thus for example, pin 126 is intended to extend through positive electrode alignment holes 72, pin 130  
5 through positive electrode alignment holes 74 and separator alignment holes 96, pin 132 through negative electrode alignment holes 72' and separator alignment holes 98, and pin 128 through negative electrode alignment holes 74'.

**[0045]** The stacking fixture in Figure 9 enables the clips of the positive column 90 to all be secured together, as for example by laser welding. Similarly, the  
10 clips of negative column 92 can also be secured together, as by laser welding. The registration pins can be removed from the stack prior to final assembly, or alternately they can remain in the finished stack to enhance rigidity. Various pin configurations can be used, particularly including fasteners which can be locked in place as by diameter expansion. In the final assembly of the battery when the  
15 electrode assembly is mounted in case 22, the respective current collectors are electrically connected to terminals 26, 28 (Figure 1).

**[0046]** Figure 8A illustrates a top view of the stack as viewed in Figure 6 and shows areas 140 and 142 extending along the tops of the clips on which welds can formed to secure each column of clips both mechanically and electrically.  
20 Figure 8B depicts a side view of the tab/clip portion of the stack showing an area 144 incorporating clip side ends which are also preferably welded together to secure electrical and mechanical interconnection. It should be noted that both Figure 8A and 8B show how each clip abuts an adjacent clip in its column to

facilitate welding and to assure the fabrication of a dense stack which is able to fully utilize the interior volume of the battery case and thus maximize power density performance. As previously noted, each clip preferably has a thickness approximately equal to the sum of the thickness of one positive electrode, one negative electrode, and two separators.

**[0047]** Attention is now directed to Figure 10, which illustrates an alternative clip 160 for mounting on a substrate tab 162. The embodiment of Figure 10 differs from the embodiment of Figure 5 in that the alignment holes 164, 166 are noncircular, e.g., rectangular. Other noncircular holes can also be used. If noncircular holes are used, positive and negative electrode registration can be achieved using only one alignment hole per clip.

**[0048]** Attention is now directed to Figure 11A, which shows a modification of the clip previously shown in Figures 3, 4, and 5. In the clip 170 of Figure 11A, an opening 172 is formed along the clip foldline 174 between the alignment holes 176 and 178. The opening 172 exposes a portion of the substrate 180. When the clips 170 of Figure 11A are utilized in a stack as shown in Figure 11B, the aligned openings 172 form slots 184 and 186 in the respective positive and negative clip/tab columns. By so exposing edge portions 180 of the substrate tabs, an enhanced weld can be produced within the slot areas 184, 186 to provide even better electrical and mechanical interconnection of the stack elements.

**[0049]** Figure 12 illustrates a still further variation in which an integral two panel separator 190 is provided. More particularly, the separator 190 includes

panels 192 and 194 which are bent around a foldline 196. The two panel separator 190 can be used in a stack in place of two separate separators to facilitate fabrication and further enhance electrical separation of adjacent electrodes.

- 5   **[0050]**   From the foregoing it should now be understood that an enhanced electrode assembly and its preferred manner of fabrication in accordance with the invention have been described. Although only a limited number of specific preferred implementations have been disclosed, it should be recognized that insubstantial modifications and equivalents will occur to those skilled in the art
- 10   which fall within the spirit and intended scope of the appended claims.